OHIO STATE UNIVERSITY

An Investigation of a Selected Group of Cataclastically Deformed Rocks by Petrographic and X-Ray Diffraction Methods

by

Gary A. Lund

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE

Senior Thesis Advisor

Dr. John F. Sutter

Columbus, Ohio

May, 1972

ABSTRACT

AN INVESTIGATION OF A SELECTED GROUP OF CATACLASTICALLY DEFORMED ROCKS BY PETROGRAPHIC AND X-RAY DIFFRACTION METHODS

Gary A. Lund

A suite of rocks from the Kings Canyon Shear Zone, located in the Northgate fluorspar district in Jackson county, Colorado, was made available for study by Dr. John F. Sutter, Ohio State University. The investigation of these rocks was limited to the mineralogical and textural changes observed by the use of the petrographic microscope and by X-ray diffraction. Previous studies by Dr. Sutter have been mainly concerned with K/Ar age dating and the geochemistry of these cataclastically deformed rocks. His findings show a decrease in apparent age of the rock from both sides of the shear zone toward the center, and he attributes this to increasing neomineralization toward the center of the shear zone.

The samples of cataclastic rock in the suite are, for the most part, derived from a common parent rock type, a hornblende gneiss. The rocks sampled occur at various locations within the shear zone, and they exhibit very well the changing degrees of cataclastic degradation such as granulation, recrystallization, and neomineralization. Intergranular and intragranular strain features are apparent in all the samples. Three samples, which occur in the central portion of the shear zone, have a very different texture, mineralogy, and chemistry than the other samples of cataclastic rock in the shear zone. The apparent K/Ar ages of these anomalous samples also, according to Dr. Sutter, do not conform with the ages of adjacent cataclastic rocks which were derived from the hornblende

gneiss. Some extra emphasis was made in this study to determine the origin of these rocks on the bases of mineralogy and texture. In general, all samples show increasing recrystallization and neomineralization as they approach the center of the shear zone.

TABLE OF CONTENTS

INTRODUCTION

The cataclastic rock samples in this study come from the Kings Canyon Shear Zone, located in the Northgate fluorspar district in Jackson county, Colorado. The shear zone runs through a Precambrian gneiss complex which is a portion of the core of the Medicine Bow Mountains in north central Colorado. The parent rock of this suite of cataclastic rocks is, for the most part, a hornblende gneiss. Several samples in the central portion of the shear zone (KCSZ-13, 14, and 14A) seem to have been recrystallized from a different parent rock, or they are a result of syntectonic or post-tectonic fluids partially metasomatizing the parent rock to produce the different mineralogy, texture, and chemistry (Sutter, 1969).

The majority of the samples show cataclastic deformation of the parent hornblende gneiss. Quite a variation in texture and mineralogy is observed when examining these samples; this variation is due to differences in the mechanism of cataclastic deformation. The deformation passes from principally granulation with little recrystallization at the outer edges of the shear zone, through increasing recrystallization and increasing granulation as the center of the shear zone is approached, to increasing neomineralization and recrystallization in the proximity of the center of the shear zone. The sample KCSZ-12 at the center of the zone is completely neomineralized (and recrystallized).

Most of the terminology in this paper is restricted to well known (petrographically) specific vocabulary. There has been much dispute and ambiguity in the use of the terms "mylonite", "ultramylonite", "cataclasite", "mylonite schist", "augen schist", "mylonite gneiss", "flaser rocks", "blastomylonite", etcetera, to describe cataclastically deformed rocks.

Many of these terms are synonomous, and all of them reflect, for a given parent rock and tectonic event, various stages of degradation in terms of granulation, recrystallization, neomineralization, and metasomatism. The term "mylonite", in general, should be used, according to Dr. Sutter, only for rocks which meet all three of these criteria: coherence, evidence of granulation, and structural position in a plane between two bodies of rock which have undergone differential movement. In this paper, the term "mylonite" has not been used by itself. Descriptive adjectives, common to petrology, have been used as suggested by Dr. Sutter. The terms which I have used and which may need clarification are 1) porphyroclastic mylonite, 2) laminated mylonite, 3) metasomatized mylonite, and 4) blastomylonite.

1) Porphyroclastic mylonite: little recrystallization; mainly mechanical granulation; anhedral single to lenticular aggregates of resistant, relict minerals; slight foliation may be present.

2) Laminated mylonite: recrystallization more dominant; segregation of minerals into layers (foliation); granulation textures still evident in porphyroclastic relict grains.

3) Metasomatized mylonite: partial or total recrystallization or neomineralization due to fluids or gases; great variation in mineralogy over short lateral and vertical distances; foliation may or may not be present.

4) Blastomylonite: complete recrystallization and neomineralization; no relict grains; foliation (lamination) may be present often.

The rocks in this study were sampled by Dr. Sutter in the following manner: The shear zone is about 130 feet wide at the road cut where sampling took place. Each sample's position was measured in relation to the other's and in a distance perpendicular to the layering in the zone. Sample KCSZ-1 was taken from an amphibolite layer 50 feet above the shear zone. Samples KCSZ-3 to KCSZ-20 were taken sequentially from the edge of the shear zone to the center and then out again to the opposite edge. Samples KCSZ-12,13,14, and14A were taken from the central area of the shear zone.

METHODS

The petrographic investigations were carried out with the use of a standard Leitz Wetzlar, turret objective, petrographic microscope, which was provided by the Ohio State University Geology Department. The samples were thin-sectioned previously by Dr. Sutter.

The X-ray diffraction was done on a General Electric XRD-6 unit in the Geochronology and Isotope Geology Laboratory at Ohio State University. Selected, powdered, whole-rock samples of the Kings Canyon Shear Zone, provided by Dr. Sutter, were analyzed for the major minerals. In all samples, the spectrum was scanned from 5° to 40° or 50° 2θ, at 1°/minute, and 1000 cps. Cu$k\alpha$ was the x-ray source, and the high voltage was set to 45 Kv; the current was set to 16 milliamperes.

MINERALOGY AND TEXTURE OF SAMPLES

KCSZ-1

Principal minerals: hornblende, plagioclase, and small amount quartz.

Texture: hornblende and feldspar grains are equidimensional, large to medium sized; quartz appears as medium to small sized but is not abundant. Hornblende is subhedral to anhedral; grain edges are somewhat granulated; polysynthetic twinning is observed in several grains; cleavage traces are straight; poikiloblastic texture with inclusions of quartz is seen; pleochroic, light yellow-bluish green-brownish green (olive).
Plagioclase is mainly anhedral laths; polysynthetic twinning of the Albite-Carlsbad-Pericline laws common, but some plagioclase shows twinning lamellae only at grain boundaries; twinning lamellae are usually bent and curved but not severely; minor sericitization of plagioclase along twin plane boundaries; An_{32} content based on Michel-Levy's method.
Quartz is anhedral, strained (undulatory extinction).

KCSZ-3

Principal minerals: quartz, biotite, Na-plagioclase, K-feldspar, white mica, myrmekite, chlorite, and trace epidote.

Texture: mostly fine grained but some small to medium sized grains occur as porphyroclasts; all grains are anhedral except biotite, which occurs as small prismatic laths.
Biotite is in preferred orientation throughout most of the thin section as parallel to subparallel laths interdispersed in a quartzo-feldspathic matrix; biotite "layers" bend around the occaisional porphyroclasts of feldspar and lenticles of quartz-K feldspar-plagioclase-myrmekite; areas of microfolding and shearing are shown by the orientations of biotite in certain areas of the thin section (Plate 1); biotite is often chloritized; a reflection on the parent hornblende gneiss is shown by the segregation of quartz-feldspar-biotite "zones" by zones of predominantely quartz-feldspar (with little biotite).
Quartz occurs mainly as finely granulated clastic grains; these grains show undulatory extinction as a rule; quartz also occurs in slightly larger grain size near the porphyroclastic lenticles of feldspar; quartz also is found as a train of medium sized recrystallized grains.
Feldspar, being evidently the most resistant to cataclastic granulation, is found as porphyroclasts of untwinned albite(?) and K-feldspar; sericite is on most of the feldspar grains, including those in the matrix.
Epidote, in very small amounts, is found scattered throughout the thin section but is usually near biotite.

KCSZ-4

Principal minerals: quartz, biotite, feldspar (sericitization abundant), and trace epidote.

KCSZ-4 continued

Texture: extremely fine grained, equigranular rock composed of granulated (cataclastic) quartz and feldspar, both minerals are anhedral. Biotite occurs in parallel to subparallel, small, prismatic laths; biotite orientations show folding in large areas of the thin section (Plate 2); some chloritization of biotite.
Epidote is scattered throughout the section but is usually near biotite; epidote is fine grained.
Some recrystallized quartz occurs as a medium grain size, lenticular aggregate which cross-cuts the biotite "fold layers"; it shows undulatory extinction.
Occasional porphyroclasts of feldspar, covered by a reddish opaque.
Occasional opaques.
Texture of rock shows increasing granulation compared to KCSZ-3.

KCSZ-4A

Principal minerals: quartz, plagioclase, sericite, biotite, chlorite (penninite?), k-feldspar?, opaques, and epidote.

Texture: fine grained quartz and feldspar, anhedral, undulatory extinction, the result of granulation.
The quartzo-feldspathic matrix is interlaced by biotite laths, which are fine grained and have parallel orientation; there is complete chloritization of biotite in certain areas of the thin section-- mainly near the numerous shear zones which occur in the rock; the chlorite is very pleochroic in greens and occurs usually as anhedral, lengthy blebs; the chlorite also occurs along fractures in the rock, and in one instance, appears to be replacing a relict silicate porphyroclast.
Occasional porphyroclasts of Na plagioclase (probably) occur, and there are lenticles of plagioclase and medium grain size quartz (clastic).
Sericitization of the feldspar in the matrix and along shear planes is abundant.

KCSZ-5

Principal minerals: quartz, plagioclase, muscovite, sericite, chlorite (and chloritized biotite), K-feldspar, epidote, and opaques.

Texture: fine grained matrix of quartz and K-feldspar which is cataclastic; numerous porphyroblasts of plagioclase and some of K-feldspar; some porphyroclasts of plagioclase remain; quartz and feldspar also occur as patches and trains of recrystallized, interlocking grains; biotite, although it is scattered throughout the section in sparse amounts, occurs mainly near areas of fracture which are filled with chlorite and numerous epidote grains.
In general, rock does not show much, if any, foliation or microfolding.
Numerous porphyroblasts suggest recrystallization is starting to appear over cataclastic texture.

KCSZ-6

Principal minerals: quartz, plagioclase, microcline, orthoclase, biotite, sericite, chlorite, muscovite.

Texture: heteroblastic, the grain sizes alternate from the fine grained quartzo-feldspathic matrix to the medium and large grain sizes of quartz in crystalloblastic trains and feldspars in metacrysts; metacrysts seem to be divided between porphyroclastic and porphyroblastic origins -- some are clear with straight twin planes, some are clear with bent twin planes and some inclusions, and some are very sericitized; all metacrysts are anhedral; trains of recrystallized quartz occur abundantly and usually curve around the large metacrysts; biotite is parallel with these quartz trains.
Recrystallization of quartz (and possibly feldspars) is more dominant in this sample than in previous samples.

KCSZ-7

Principal minerals: quartz, plagioclase, muscovite, biotite, and trace sphene.

Texture: similar to KCSZ-6, but has much more muscovite and biotite; a combination of mechanical granulation and recrystallization textures.

KCSZ-8

Principal minerals: quartz, plagioclase, biotite, epidote, chlorite, sericite, and K-feldspar (?).

Texture: a combination of granulation of feldspar metacrysts (both relict and recrystallized ones) and recrystallization of quartz and feldspar -- it is difficult to determine the extent recrystallization versus mechanical granulation.
Quartz trains are parallel to subparallel.
Numerous micro-shear zones have granulated quartz and feldspar with parallel biotite flakes altering to chlorite.
Epidote is also found with biotite in the shear zones.

KCSZ-9

Principal minerals; quartz, Na plagioclase, biotite, chlorite, epidote, sericite, orthoclase, microcline, opaques, trace sphene, and trace muscovite.

Texture: the thin section can be divided into three zones based on the mineralogy and fabric.

KCSZ-9 continued

Zone 1: epidote and quartz are the essential minerals; epidote is subhedral to anhedral and appears clear; epidote constitutes approximately 50% of this zone; quartz occurs as anhedral stringers and lenticular masses; epidote and quartz show undulatory extinction, but quartz does not appear granulated as much as epidote; epidote-quartz zone has a distinct boundary from Zone 2.

Zone 2: quartz, plagioclase, epidote, sericite, chlorite, microcline, orthoclase, and trace sphene are the essential minerals; quartz occurs as recrystallized, parallel trains running through a fine grained, granulated quartzo-feldspathic matrix; there is much sericitization of the feldspar in the matrix; the quartz trains run around lenticular porphyroclasts of sericitized feldspar and granulated quartz; large lenticular plagioclase porphyroblasts occur parallel to the quartz trains, and some have relict centers of sericitized feldspar and epidote; some large porphyroclasts of orthoclase and microcline occur as lenticles, parallel to the foliation (of quartz trains); there are also large, square shaped porphyroclasts of sericitized plagioclase.
Texture is porphyroclastic, in general, but recrystallization of quartz and feldspar is evident.

Zone 3: is separated from Zone 2 by a chlorite -biotite occurence at the "boundary"; epidote also is common along this boundary (1 large subhedral porphyroblast is seen along with many smaller grains); biotite, altering to chlorite, occurs as subparallel laths in a fine to medium grained quartzo-feldspathic matrix; some large chlorite grains and some epidote also occur in this matrix; the feldspar is almost all very sericitized, indicating predominantely cataclastic mechanical degradation, but some large, clear grains of feldspar are probably porphyroblastic.
FOR WHOLE ROCK: abundance of neomineralized epidote is most striking feature.

KCSZ-10

Principal minerals: quartz, plagioclase, muscovite, K-feldspar (microcline?), sphene, epidote, occasional biotite altering to chlorite, sericite.

Texture: recrystallization of quartz and feldspar occurs along with mechanical or clastic degradation of these minerals; quartz trains of varying width occur in parallel lines except where they go around porphyroblasts of feldspar; some porphyroclasts remain but are highly fractured and altered to sericite, epidote, and muscovite; porphyroblasts are subhedral to lenticular plagioclase and K-feldspar; one particularly large plagioclase porphyroblast dominates the thin section-- it is lenticular with granulated grain boundaries, internal fractures, and granulated zones running through the grain; most porphyroblasts are clear but some have partial sericitization; there is a large sericitized feldspar zone, adjacent to the "giant" porphyroblast, which also has chloritized biotite, epidote, muscovite, and sphene as associated minerals; granulated fine grained quartz remains between the quartz trains.

KCSZ-11

Principal minerals: quartz, epidote, muscovite, and trace sphene.

Texture: blastomylonitic (completely recrystallized and neomineralized); no porphyroblasts or porphyroclast are seen; dominant minerals are quartz and epidote; quartz trains are in parallel throughout most of the thin section; epidote and muscovite are dispersed between the quartz trains; sphene is randomly scattered in rock and is usually euhedral.
This sample shows more recrystallization and neomineralization than any previous samples.

KCSZ-12

Principal minerals: quartz, epidote, muscovite, some albite, some orthoclase, and trace sphene.

Texture: blastomylonitic; porphyroblasts are occasionally seen; quartz occurs as trains in parallel orientation which are wider and more continuous than those in KCSZ-11; between the recrystallized quartz trains are finer grained quartz (new), epidote, plagioclase, muscovite, and trace sphene; the porphyroblasts are not large--they occur between the quartz trains; albite, orthoclase, and epidote are the minerals of the porphyroblasts; there is one relict porphyroclast which has been entirely converted to muscovite, it is large and lenticular; epidote porphyroblasts are subhedral to lenticular with granulated edges; orthoclase and plagioclase porphyroblasts are subhedral and partly sericitized.
Recrystallization and neomineralization are complete in this sample, when compared to the parent hornblende gneiss.

KCSZ-13

Principal minerals: quartz, epidote, muscovite (sericite), sphene, and chlorite.

Texture: large portion of sample is mainly medium to coarse grained, anhedral to euhedral epidote which is associated with wide trains of medium to fine grained, recrystallized quartz; epidote is fresh in appearance; this quartz-epidote area has scattered sphene crystals.
The rest of the thin section is made of quartz trains of varying width and linearity; between these trains are ground up, lenticular, and streaked out porphyroblasts--this "interband" material consists mainly of sericite, muscovite, epidote, sphene, and chlorite; sericite, epidote, and sphene appear streaked out, ground up, and lenticular-- they are probably syntectonic with post-crystallization granulation; chlorite, which occurs in quite large laths locally in the section, and muscovite (also as laths of medium size) seem to be late syntectonic to post-tectonic because of their lack of deformation and their orientations which are non-parallel to the quartz trains (Plate 3).

KCSZ-13 continued

Sphene, which appears as granulated, lenticular, and streaked out "interband" material, occurs abundantly in certain areas of the thin section; sphene also is scattered elsewhere through the section as well. Several fracture sets occur in the rock, and they all have a particular orientation to the quartz band foliation (Plate 4); these fractures are mostly empty, but some are epidote filled; the fractures crosscut most of the quartz trains in the thin section, and they extend from the epidote-quartz zone, previously mentioned, through the entire slide; the fractures seem to be very late syntectonic to post-tectonic in origin. Overall texture of rock is blastomylonitic, laminated, with relict porphyroclastic material streaked out and neomineralized between the quartz trains; the abundance of epidote and sphene, and lack of feldspar, denote this advanced neomineralization; there is late stage crystallization of chlorite and muscovite, and late stage fracturing.

KCSZ-14

Principal minerals: epidote, muscovite, orthoclase, plagioclase, and quartz.

Texture: foliation is not evident; rock is composed mainly of anhedral, medium grained epidote with interdispersed medium grained, subhedral muscovite; some areas of the thin section have recrystallized, anhedral orthoclase which is sericitized to some extent.
Large area near edge of slide consists of recrystallized, very large grained, anhedral plagioclase which often has fractured, offset, and bent twin planes; this plagioclase has poikiloblastic inclusions of unstrained quartz, it is sericitized, and there are some albite-epidote intergrowths. Lack of foliation, which was previously shown in other samples by trains of recrystallized quartz, is the most striking feature of this sample. Lack of abundant quartz is also unusual, when compared to the previous samples.

KCSZ-14A

Principal minerals: epidote, quartz, and muscovite.

Texture: foliation is evident again; quartz trains of varying width (up to 1.5 mm. for certain aggregates of trains) occur in parallel orientation except where they wrap around granulated lenticles of neomineralized epidote; this epidote has been streaked out into bands of anhedral to subhedral, medium to fine grains, interlaced with fine grained quartz; muscovite occurs as non-oriented, medium sized, anhedral laths in a "band" adjacent to one of the lenticular epidote porphyroblasts; muscovite is late stage syntectonic or post-tectonic in origin.
Several zoned, nearly euhedral crystals of epidote were found--these are late stage (Plate 5).
Overall texture is laminated, blastomylonitic.

KCSZ-15

Principal minerals: quartz, muscovite (including sericite), some epidote, and trace chlorite.

Texture: wide trains of strained quartz throughout the thin section in parallel orientation except around lenticular porphyroclasts which have been neomineralized to sericite, muscovite, and epidote; former granulated porphyroclastic material, which has been streaked out into the areas between the quartz trains, has been neomineralized to muscovite epidote, and fine grained quartz; muscovite is aligned to foliation as in KCSZ-13 (Plate 3).
In general, texture is nearly complete neomineralization (blastomylonitic), laminated; quartz trains alternate with bands of muscovite and lesser epidote; porphyroclasts are almost entirely gone.
This sample is similar to KCSZ-11 in mineralogy and texture.

KCSZ-17

Principal minerals: quartz, muscovite, microcline, albite, carbonate, and small amount fluorite.

Texture: very coarse grained, foliation not apparent; very large metacrysts of albite and microcline dominate the thin section; these grains appear relatively clear, fractured, and anhedral; quartz is generally smaller in size, varying from coarse to fine; muscovite occurs as large, lathlike grains which are deformed slightly (bent); feldspars are fractured internally as shown by offset twin planes; carbonate is dispersed veinlike through the feldspar grains, and it is also found as intergrain fillings; fractured quartz and feldspar often appear "floating" in a carbonate matrix; fluorite occurs locally within the carbonate matrix (Plate 6).
The texture appears mainly as cataclastic mechanical degradation, but some recrystallization has taken place (muscovite).

KCSZ-18

Principal minerals: quartz, microcline, biotite, orthoclase, plagioclase, trace muscovite, and trace epidote.

Texture: mainly cataclastic mechanical breakdown, but there is some recrystallization apparent; lenticular, quartzo-feldspathic porphyroclasts occur in the sample; the feldspars in these are microcline, orthoclase, and plagioclase; quartz trains are starting to form, but they are not parallel, in general, because they wrap around the lenticular porphyroclasts; biotite is parallel to the quartz trains but is not a major mineral; fine to medium grained quartz and feldspar occur between the lenticles and the quartz trains; epidote and muscovite, in small amounts, occur often with biotite; there is one extremely large porphyroblast (approximately 5 mm.) of microcline; it has poikiloblastic texture with inclusions of orthoclase, biotite, and myrmekite; myrmekite is found in some lenticles as well.

KCSZ-19

Principal minerals: quartz, orthoclase, plagioclase, microcline, minor biotite, minor opaques, minor muscovite, trace epidote, sericite.

Texture: combination of mechanical granulation and recrystallization; quartz trains abundant but they are of varying thickness and are not parallel to each other--they wrap around the porphyroclasts of plagioclase, microcline, and orthoclase; there is a fine grained quartzo-feldspathic matrix between the quartz trains; small laths of biotite are in parallel orientation to the quartz trains; trace epidote occurs with the biotite; the feldspar porphyroclasts are usually lenticular, with granulated edges; myrmekite intergrowths occur occasionally; the feldspar in the matrix is sericitized quite a bit, but the porphyroclasts have less sericite alteration.
Overall texture is generally coarse grained, lenticular porphyroclastic, with uneven laminations of quartz and biotite.

KCSZ-20

Principal minerals: quartz, plagioclase, microcline, orthoclase, biotite, minor epidote, trace zircon, trace myrmekite, trace tourmaline, trace sphene, and sericite.

Texture: mainly mechanical granulation; porphyroclastic feldspars vary from anhedral square to lenticular, and they are often sericitized; porphyroclasts are usually fractured, granulated, and often have bent twin planes; myrmekite occurs in some porphyroclasts; feldspar lenticles grade into a fine grained quartzo-feldspathic matrix; trains of recrystallized quartz are similar to those in KCSZ-19 but not developed as continuously; biotite is parallel to the quartz trains; sphene, epidote, and tourmaline are partly euhedral and partly fractured; little recrystallization has taken place besides that of quartz, biotite, and the trace minerals.

PLATES

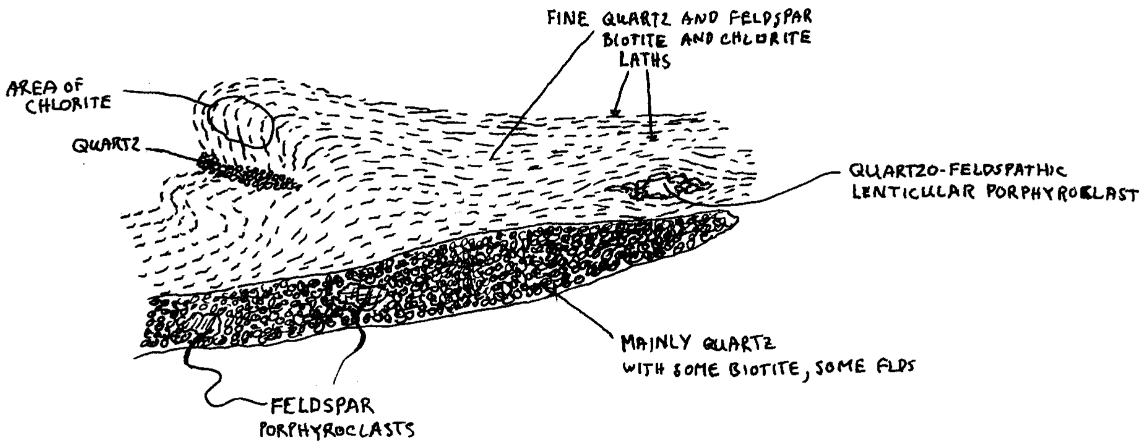

PLATE 1 KCSZ-3

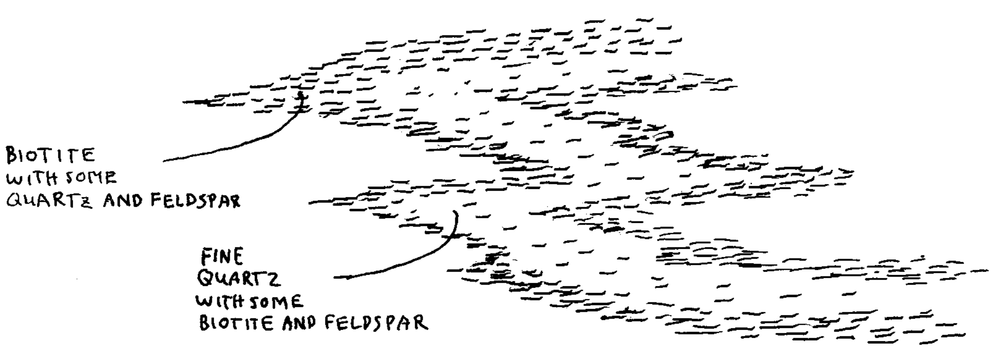

PLATE 2 KCSZ-4

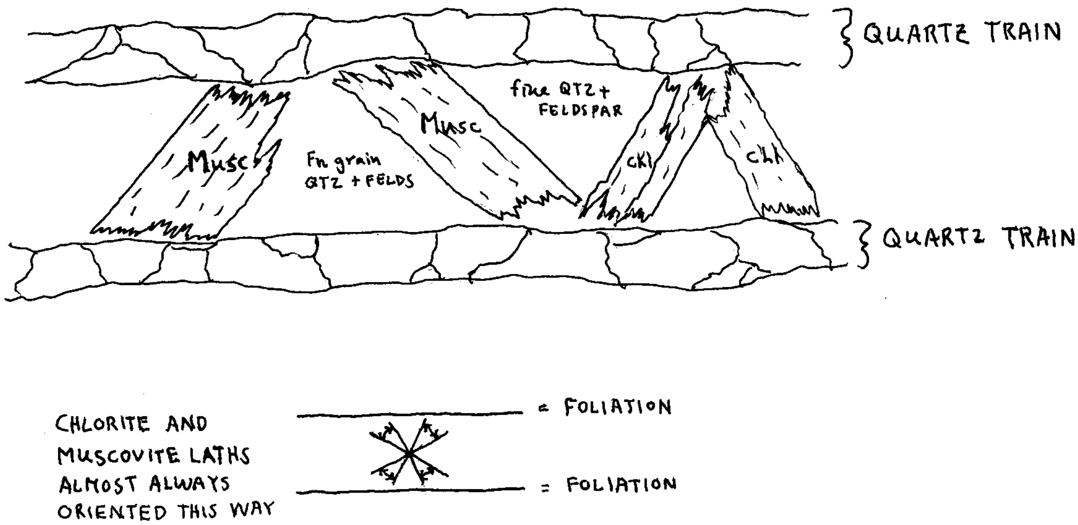

PLATE 3 KCSZ-13

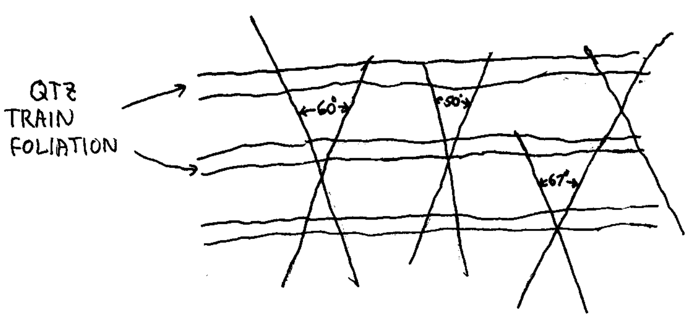

PLATE 4 KCSZ-13

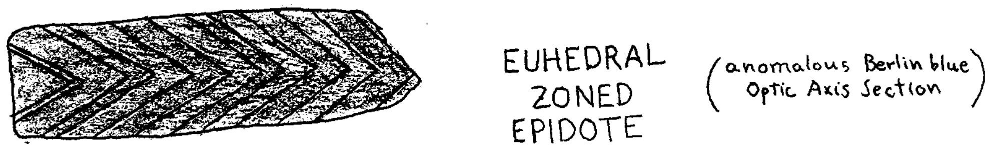

PLATE 5 KCSZ-14A

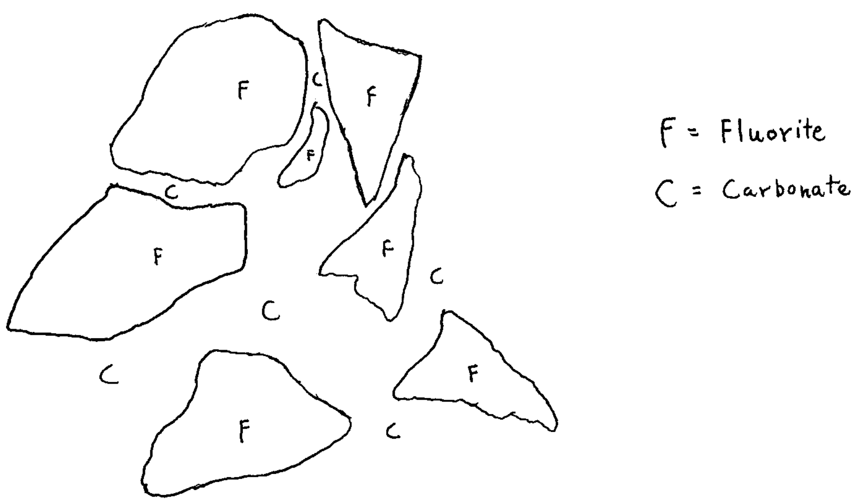

PLATE 6 KCSZ-17

X-RAY DIFFRACTION INVESTIGATION

The X-ray diffraction investigations were intended mainly to determine the principal minerals in certain samples of the cataclastic rock from the shear zone. The samples selected for study included those which have finely granulated texture (KCSZ-4, 4A), those which show unusual mineralogy (KCSZ-13, 14, 14A), and a sample ofamphibolite outside the shear zone, in which Dr. Sutter dated the hornblende by K/Ar methods.

The samples were X-rayed using a setting of 1000 cps and a $1^{\circ}\,2\theta$/minute scan rate. Unfortunately, due to the inexperience of this writer with X-ray diffraction methods, this setting proved to be insufficient to easily determine the minerals. The only minerals which the low, narrow peaks indicated with certainty were quartz, feldspars (in general), and epidote (when present in large amounts as in KCSZ-13, 14, and 14A). The "noise" was too high and the peaks were too low for minerals in lesser amounts (less than 30%, approximately) to be determined. In sample KCSZ-1, which was determined by optic methods to contain hornblende, plagioclase, and quartz, the hornblende which occurs abundantly in the sample, did not occur in the X-ray diffraction spectrum.

The experiments should be carried out again with a scan rate around $\frac{1}{4}^{\circ}\,2\theta$/minute and a sensitivity of around 100 or 500 cps. Time requirements did not allow the samples to be analyzed again.

CONCLUSIONS

From the petrographic data, it is seen that shear stress has an effect on the recrystallization of minerals in cataclastic rocks. Since there is increasing recrystallization and neomineralization towards the center of the shear zone, the frictional heat generated by the shearing of one rock body past another is assumed to be greatest near the center of the shear zone. Directed stress, in itself, also must play a part in the recrystallization and reorientation of minerals into laminations.

The problem of the origin of the rocks sampled in KCSZ-13,14, and 14A is difficult. The relative crystallization time of epidote in these samples and in KCSZ-9, 11, and 12 may provide a clue to the origin. KCSZ-9 is the first sample to contain abundant epidote as one approaches the center of the shear zone. The epidote in this rock seems to be late syntectonic because of its clear texture and its granular to subhedral form. One large subhedral porphyroblast occurs in addition to the massive anhedral to subhedral epidote in the epidote-quartz zone. The epidote in KCSZ-11 also occurs in abundance as "interband" filling. The probable origin of this epidote is the breakdown of plagioclase after it has been granulated and streaked between the quartz trains, i.e., late syntectonic. The epidote in KCSZ-13 varys from medium to coarse grained, anhedral fractured to euhedral in form, and it is fresh in appearance. There are fractures throughout the rock which cross-cut all quartz trains. These are post-tectonic and could be the result of the release of stress. Most of these fractures are empty, but one is epidote filled. These facts indicate two possible periods of epidote crystallization. The first caused the present anhedral, fractured epidote and was probably syntectonic; the second generation epidote is shown by the euhedral grains and the post-tectonic fracture filling. The second stage of epidote crystallization was probably early post-tectonic. In KCSZ-14, the lack of foliation leads one to believe that the crystallization of epidote in this rock may have been post-tectonic. The medium sized, anhedral grains support this claim somewhat. The epidote in 14A occurs in a way similar to 13. There is anhedral fractured epidote which is streaked into bands between the quartz train foliation and leads into interband porphyroblasts of epidote; this is syntectonic. There are also euhedral, zoned crystals of epidote in the rock, indicating post-tectonic growth.

The writer is inclined to favor a theory of two stage crystallization: syntectonic, due to plagioclase breakdown; post-tectonic due to partial metasomatism. If an amphibolite parent rock slice in the shear zone is considered to be the cause of the mineralogical variances, the two stage crystallization might not be apparent.

ACKNOWLEDGMENTS

I would like to express my deep appreciation to Dr. John F. Sutter for his great interest and assistance in this thesis. He generously made available the thin-section and X-ray diffraction samples, and, in addition, he provided much valuable information concerning the field relations of the area sampled. This thesis would not have been possible without his help.

I also want to thank Edward Tremba, a graduate student in the Ohio State University Geology Department, for his kind help in the operation of the X-ray diffraction unit.

REFERENCES

Chao, G.Y., "2θ (Cu) Table for Common Minerals", Carleton University Dept. of Geology, Geological Paper 69-2, (1969).

Hsu, K.J. (1955) "Granulites and mylonites of the region about Cucamonga and San Antonio Canyons, San Gabriel Mountains, California", Univ. of Cal. Pub. in Geol. Sci., v. 30 no. 4, pp. 223-352.

Kerr, P.F. (1959), "Cptical Mineralogy", third ed., McGraw-Hill, 442p.

Moorhouse, W.W., (1959),"The Study of Rocks in Thin Section", Harper and Row, publishers, 514 p.

Sutter, J.F., (1969), "Application of the K/Ar Method to the Dating of Cataclastically Deformed Rocks", PhD. Thesis, Rice University, Houston, Texas.